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# Improved Fuel Efficiency through Adaptive Radio Frequency Controls and Diagnostics for Advanced Catalyst Systems

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DOE Merit Review, Washington DC
June 2017

Filter Sensing Technologies Inc.

ID#: ACS099

# Overview

## Timeline

- **Project Start: October 2015**
- **Project End:  December 2017***
- **Percent Complete: 50%**

**No cost extension for BP1 may also extend project end date.*

## Barriers

- Emission controls are energy intensive and costly
- Lack of "ready-to-implement" sensors and controls
- Durability of 120K miles for LD and 435 K miles for HD

***Need sensors and controls to exploit efficiency potential of advanced engines!***

## Budget

- **Total Funding: $1,378,292**
  - DoE Share: $1,101,252
  - Contractor Share: $277,040
- **Total Funding**
  - Funding in FY16: $226,849
  - Funding for FY17: $665,101*

* Planned FY2017

## Partners

- **Department of Energy**
- **Corning** – *Advanced Substrates & Catalysts*
- **Oak Ridge National Lab** – *Catalyst Testing*
- **Cummins** – *HD OEM Tech. Adviser*
- **Detroit Diesel** – *HD OEM Tech. Adviser*
- **FCA** – *LD OEM Tech. Adviser*
- **DSNY (New York)** – *Fleet Testing*

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# Relevance – Project Objectives

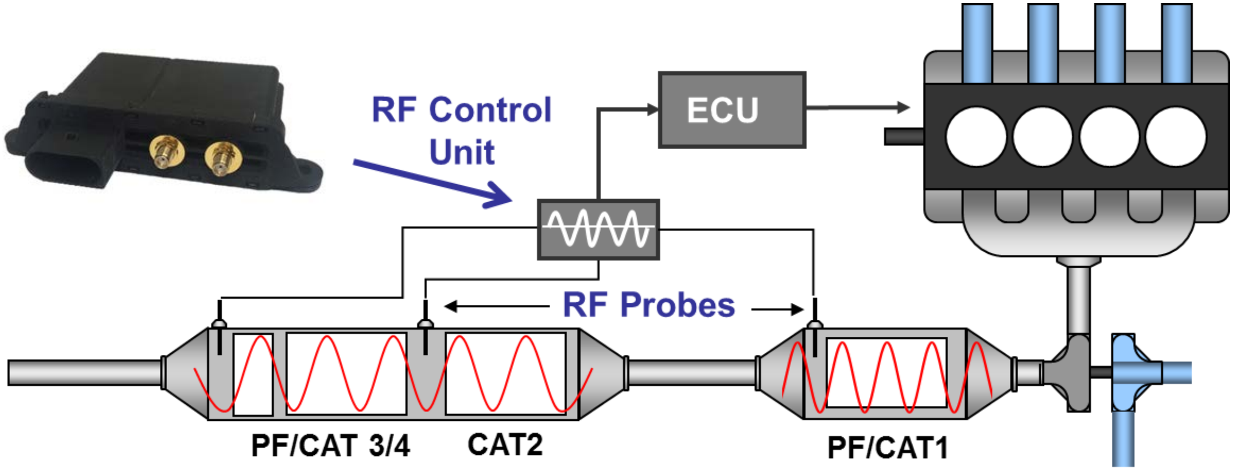
Remove Technical Barriers of aftertreatment-related fuel consumption and improve system durability, reduce system cost and complexity.

Develop RF Sensing Platform for direct measurements of catalyst state for clean diesel, lean gasoline, and low temperature combustion modes.

**The Specific Objectives of this Project Include:**

1. Develop RF sensors and evaluate the feasibility of RF sensing for the following catalysts and applications:
   - **Selective Catalytic Reduction (SCR):** Ammonia storage, *diesel & gasoline*
   - **Three-Way Catalyst (TWC):** Oxygen storage, *gasoline*
   - **Hydrocarbon Traps:** HC storage, *low temperature combustion*
2. Develop implementation strategies for the most promising applications to enable low-cost and robust emission controls to enable advanced combustion engines.
3. Demonstrate and quantify improvements in fuel consumption and emissions reduction through RF sensing in engine and vehicle tests with industry and national laboratory partners.

# Relevance – Proposed Technology and Concept




- Direct measurement of multiple catalysts
- Adaptive feedback controls adjusts as system ages

**CONCEPT:** Multi-function *RF sensing platform* to enable more robust and more efficient emission controls for gasoline, clean diesel and advanced low temperature combustion modes.

Technology Assessment

| Sensor Type | NOx or O2 | Ammonia | Soot (PM) | RF Sensor |
|---|---|---|---|---|
| Applications | NOx or $O_2$ Only | $NH_3$ Only | PM Only | $NH_3$, $O_2$, NOx, HC, PM, Ash |
| Catalyst State | Model/Estimate | Model/Estimate | Model/Estimate | Direct Measurement |
| Sensing Element | Active | Active | Active | Passive |

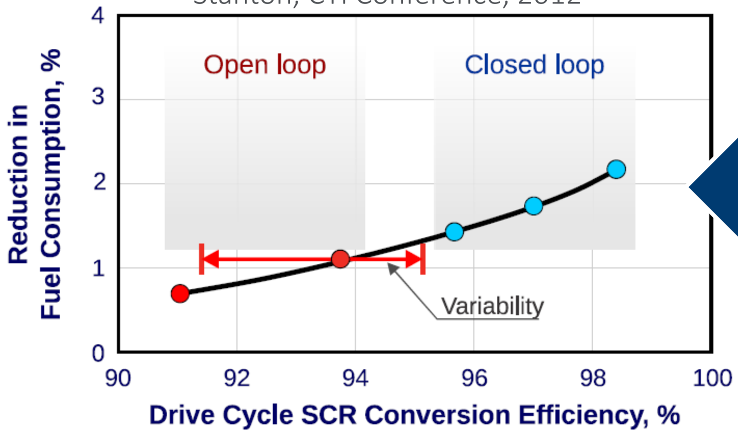
Current systems use many different types of exhaust gas sensors.

# Relevance – Efficiency Gains Enabled via Smart Aftertreatment

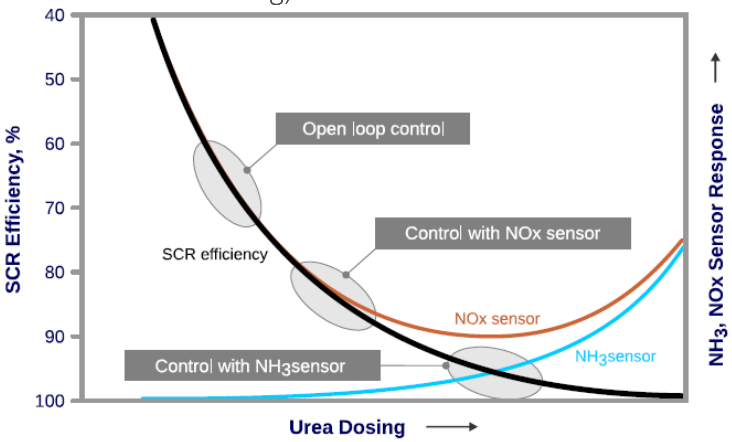
## Diesel Efficiency Gains Enabled via Improved Aftertreatment SAE 2013-0102421

| Application | High Eff. NOx AT | Reduced EGR | Reduced Backpressure | Thermal Management |
|---|---|---|---|---|
| Line Haul | 2.5% | 1.0% | 1.0% | 0.0% |
| Vocational | 2.5% | 1.0% | 1.0% | 2.5% |

Stanton, CTI Conference, 2012




Wang, SAE 2008-01-0919




## Lean Gasoline Efficiency Gains Enabled via Lean NOx Control

| Source | NOx Control | Fuel Savings vs. Stoich. | Engine Type |
|---|---|---|---|
| SAE 2011-01-0307 | PASS | 8.9% - 11.1% | SIDI V8 GM |
| SAE 2014-01-1505 | PASS | 1% - 7% (steady-state) | 2.0L Lean BMW GDI |
| ACEC Roadmap 2013 | LNT (MB), PASS (BMW) | 12% - 20% | Mercedes, BMW |

Improved sensors and controls are key enablers for more efficient use of aftertreatment to deliver additional reductions in engine fuel consumption.

# Technical Approach and Overview – Phase I

## I. Application Feasibility

- Sensor Development
- Catalyst Screening Test & Modeling

## II. Sensor Demonstration

- Sensor Optimization for Application
- Engine Dyno & Vehicle Evaluations

| FST | ORNL | Corning | DSNY | OEM | Summary of Team Roles, Tasks, and Timeline | | Year 1 | | | | Year 2 | | | | Y3 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 |
| | | | | | **Phase I - Application Feasibility** | | | | | | | | | | | |
| L | | | | | 1 | Project Management and Planning | | | | | | | | | | |
| L | | | | | 2 | Develop RF Sensors | | | | | | | | | | |
| | L | | | | 3 | Evluate Application-Specific Feasibility | | | | | | | | | | |
| L | | | | | 4 | Evaluate and Correct for Error Sources | | | | | | | | | | |
| L | | | | | 5 | Develop Calibration Functions | | | | | | | | | | |
| | L | | | | 6 | Quantify Sensor Performance | | | | | | | | | | |
| L | | | | | 7 | Year 1 Report | | | | | | | | | | |
| | | | | | **Phase 2 - Sensor Demonstration** | | | | | | | | | | | |
| | L | | | | 8 | Evaluate Optimized Sensor - Bench | | | | | | | | | | |
| L | P | P | | | 9 | Evaluate Optimized Sensor - Test Cell | | | | | | | | | | |
| | | | L | | 10 | Evaluate Optimized Sensor - Vehicle | | | | | | | | | | |
| L | | | | | 11 | Evaluate Optimized Sensor - Accuracy | | | | | | | | | | |
| L | | | | | 12 | Develop Commercialization Plans | | | | | | | | | | |
| L | | | | | 13 | Year 2 Report | | | | | | | | | | |

Work Completed    Work to be Completed    Milestone Achieved

## Project Status

- Kick-Off 10/27/2015
- Phase I focused on sensor development and feasibility
- Close coordination with ORNL, Cummins, Corning, and DSNY
- Began catalyst bench testing in Q3
- Vehicle testing ahead of schedule in Q3
- Commercialization activities ahead of schedule

Any proposed future work is subject to change based on funding levels

# Approach – Project Milestones FY16 & FY17

## Go/No-Go Decision Criteria Achieved – SCR Measurement Accuracy Target

**Milestone Summary Table**

**Recipient Name:** Filter Sensing Technologies Inc.

**Project Title:** Adaptive Radio Frequency Controls and Diagnostics for Advanced Catalyst Systems: Enabling Improved Fuel Efficiency and Reduced System Cost

| Task No. | Task Title | Type | Mile-stone | Milestone Description | Milestone Verification | Date | Quarter |
|---|---|---|---|---|---|---|---|
| **1.0** | Project Management and Planning | Milestone | M 1.0 | Plan Updated | Team Review | Mo 3 | **CPLT** |
| **2.0** | Develop RF Sensors | Milestone | M 2.0 | Sensors Developed | Team Review | Mo 6 | **CPLT** |
| **3.1** | Ammonia Storage on SCR | Milestone | M 3.1 | $NH_3$ Feasibility Report | Team Review | Mo 9 | **CPLT** |
| **3.2** | Oxygen Storage on TWC | Milestone | M 3.2 | $O_2$ Feasibility Report | Team Review | Mo 20 | **CPLT** |
| **3.3** | HC Storage on Traps | Milestone | M 3.3 | HC Feasibility Report | Team Review | Mo 21 | Q7 |
| **3.4** | Multi-Function SCR+Filter | Milestone | M 3.4 | PM/$NH_3$ Feasibility Report | Team Review | Mo 19 | Q7 |
| **4.0** | Evaluate and Correct for Error Sources | Milestone | M 4.0 | Errors Quantified | Team Review | Mo 21 | **CPLT** |
| **5.0** | Develop Calibration Functions | Milestone | M 5.0 | Calibration Complete | Team Review | Mo 21 | **CPLT** |
| **6.0** | Quantify Sensor Performance | Milestone | M 6.0 | Performance Quantified | Team Review | Mo 21 | **CPLT** |
| **7.0** | Phase 1 Report | Milestone | M 7.0 | Report Submitted | Team Review | Mo 20 | Q7 |
| | Go/No-Go Decision Point | Decision | D 1.0 | Targets Achieved | Team Review | Mo 18 | **CPLT** |
| **8.0** | Evaluate Optimized Sensor - Bench | Milestone | M 8.0 | Bench Test Complete | Team Review | Mo 24 | Q8 |
| **9.0** | Evaluate Optimized Sensor - Test Cell | Milestone | M 9.0 | Dyno Test Complete | Team Review | Mo 27 | Q9 |
| **10.0** | Evaluate Optimized Sensor - Vehicle | Milestone | M 10.0 | Vehicle Test Complete | Team Review | Mo 30 | Q10 |
| **11.0** | Evaluate Optimized Sensor - Accuracy | Milestone | M 11.0 | Accuracy Quantified | Team Review | Mo 30 | Q10 |
| **12.0** | Develop Commercialization Plans | Milestone | M 12.0 | Plans Developed | Team Review | Mo 30 | Q10 |
| **13.0** | Phase 2 Report | Milestone | M 13.0 | Report Submitted | Team Review | Mo 30 | Q10 |

**No-Cost Time Extension:** 6 Months for budget period 1 granted 11/2016

Extends BP 1 to 5/31/2017 to complete Phase I testing with project partners

Any proposed future work is subject to change based on funding levels

# Approach – Quantify Sensor Performance and Fuel Savings

## Team Member Contributions | Performance Metric

- Develop RF sensors
- Sensor calibration
- Catalyst aging

- Production gas sensors
- Storage models
- Gravimetric (PM/Ash)

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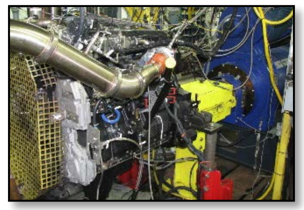
- Advanced substrates
- Model catalysts
- HD engine dyno testing



- Production gas sensors
- Emissions bench (FTIR)
- Storage models

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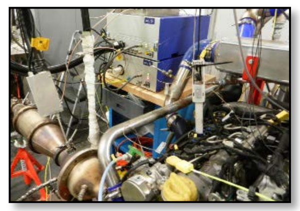
- Catalyst bench testing
- Model validation
- Engine dyno testing



- Emissions bench (FTIR)
- Adv. Instruments Spaci-MS
- Catalyst models

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- On-road fleet test
- Volvo/Mack trucks (SCR+DPF)
- 18 Months total, 2 trucks

- Stock Volvo/Mack SCR controls
- On-road durability

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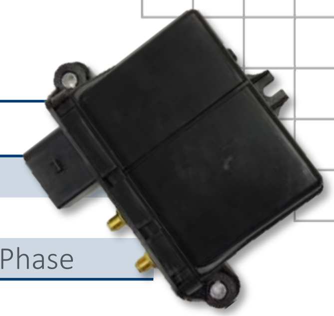
- OEM technical advisors
- Catalyst samples
- Design of experiments
- Parallel testing

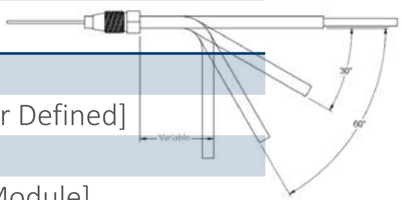
- System requirements
- Production sensors
- In-house models

# Accomplishments – Production-Intent Sensor Developed

## RF Control Unit and Antennas



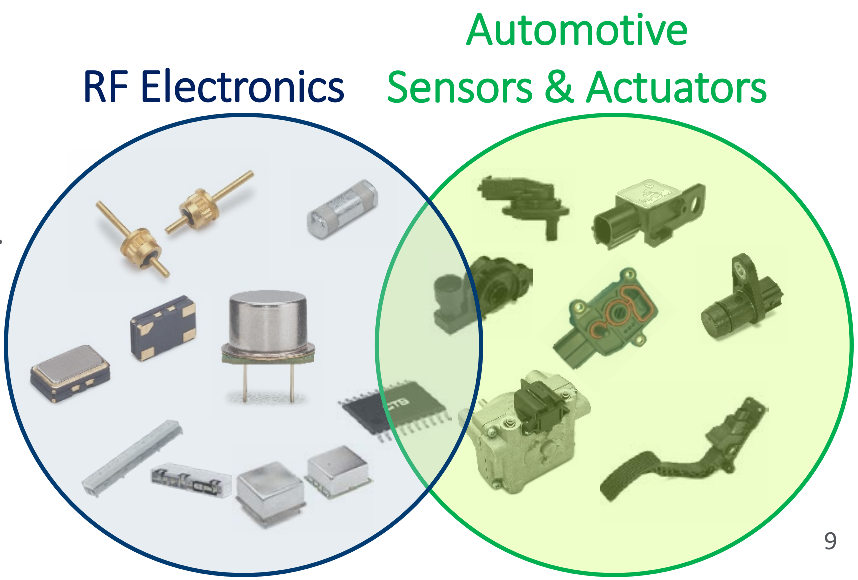
| Performance | |
|---|---|
| Scan Frequency Range: | 0.4 to 2.5 GHz |
| Measurement Update: | 1 -10 Hz typical |
| Measurement Method: | Magnitude and Phase |



| Specifications | |
|---|---|
| Electrical: | 6.5 to 36 V |
| Measurement Update: | 1 -10 Hz typical [User Defined] |
| Communication: | CAN J1939 |
| Mass: | 175 g Max [Sensor Module]<br>125 g Max [Antennas with 2m Cable] |
| Envelope: | 131 x 107 x 27.3 mm [Sensor Module]<br>150 mm Max Antenna Length |

## Commercial Milestones Achieved Ahead of Schedule – Acquired by CTS Corporation

- **Ticker:** CTS (NYSE)
- **Founded:** 1896, Chicago IL
- **Business:** CTS is a leading manufacturer of sensors, actuators and electronic components.
- **Locations:** 11 manufacturing locations throughout North America, Asia and EU.
- **Number of Employees:** ~4,000 Globally

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# Accomplishments – Catalyst Configurations Evaluated

| Catalyst | Condition | Application | Baseline | Test Conditions | Facilities |
|---|---|---|---|---|---|
| **SCR** | Degreened | Cummins 8.9L ISL (2015) | $N_2$, Air 25 °C – 400 °C | $NH_3$ Storage 150, 200, 250, 300, 350, 400°C | CTS ORNL |
| SCRF | Degreened | Non-Production *[VW]* | $N_2$, Air 25 °C – 400 °C | $NH_3$ Storage 250°C | CTS |
| SCRF | Soot / Ash | Non-Production *[VW]* | $N_2$, Air 25 °C – 400 °C | $NH_3$ Storage 250°C | CTS |
| **TWC** | Degreened | GM Malibu 2L DI (2016) | $N_2$, Air 25 °C – 400 °C | $O_2$ Storage, Lean / Rich Pulses ($C_3H_8$) | CTS ORNL |
| TWC | Degreened | Chrysler V8 (2016) | $N_2$, Air 25 °C – 400 °C | $O_2$ Storage, Lean / Rich Pulses ($C_3H_8$) | CTS |
| HC Trap | TBD | Non-Production | To be completed | To be completed | ORNL |

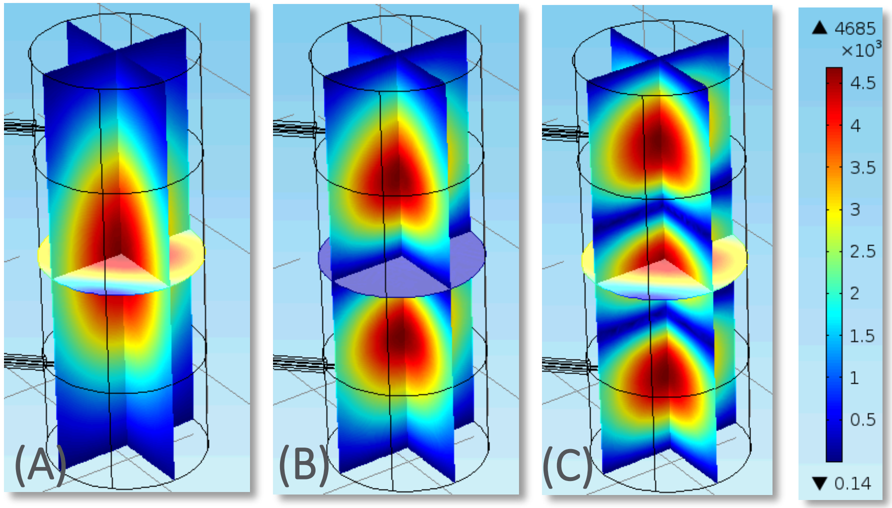
## General Catalyst Test Conditions

- Reference / baseline testing with air and inert conditions to characterize RF signal response to catalyst over temperature range
- SCR: 5-13% $H_2O$, $CO_2$; 0-10% $O_2$; 0-2% CO, $H_2$; 0-800 ppm HC, $NH_3$
- SCRF – soot/ash loading from exhaust of diesel engine and burner
- TWC: 5-13% $H_2O$, $CO_2$; 0-10% $O_2$; 0-2% CO, $H_2$; 0-800 ppm NO; 0-0.3% HC

Same catalyst core samples used with all project partners and for engine testing in Phase II.

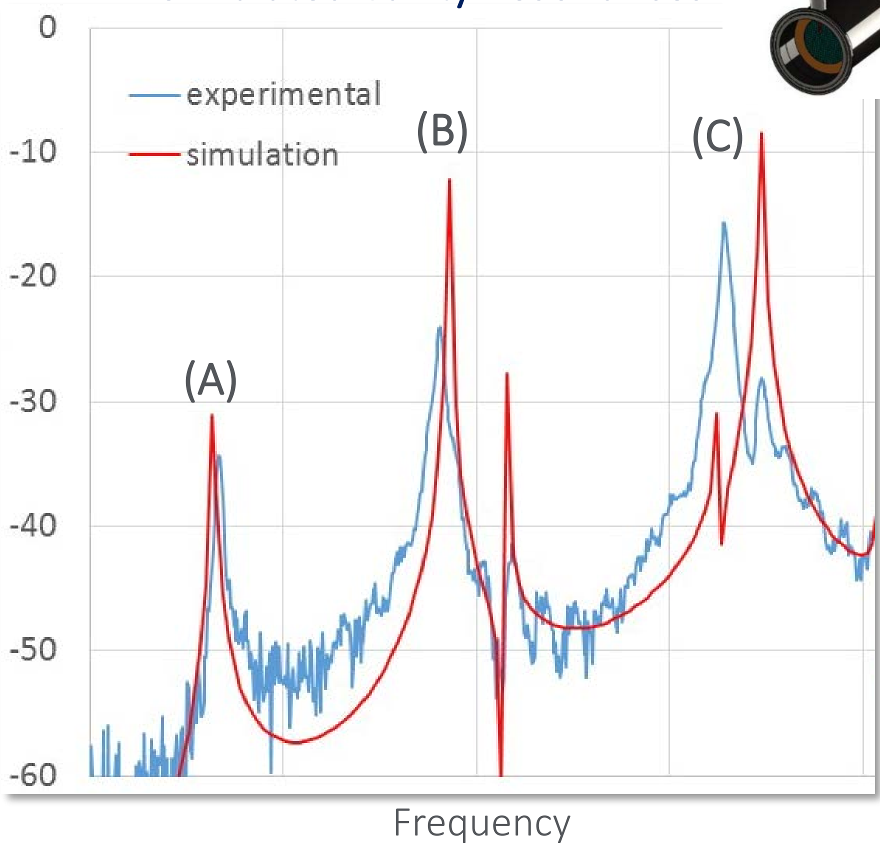
# Accomplishments – RF Cavity Simulations Validated

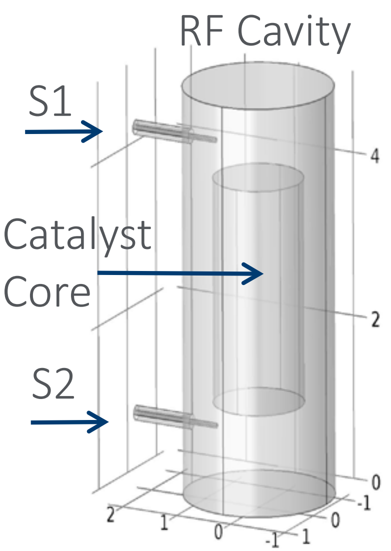
## Results of Cavity Electric Field Simulations



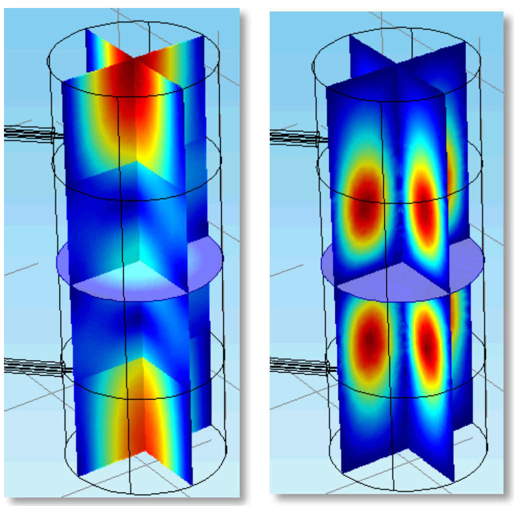

- Electric field distributions provide spatial sensitivity to monitor local storage of gas species
- Potential to monitor location of stored ammonia (front → back of SCR)

## Simulated Cavity Resonances



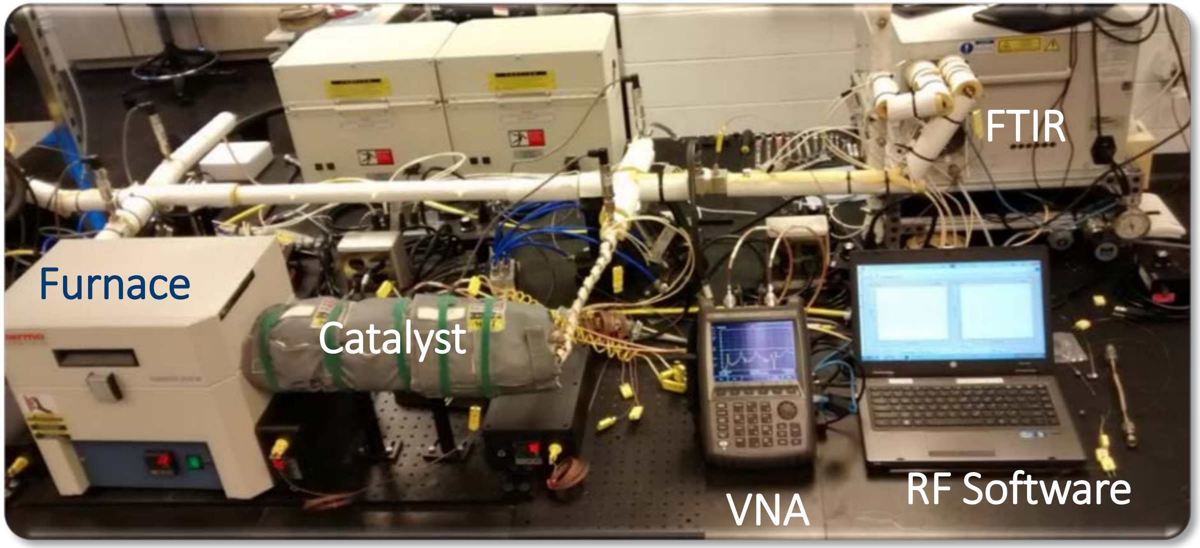




## Higher Order Modes



# Accomplishments – Multiple Bench Reactor Systems

## ORNL Bench Reactor Setup for RF Calibration

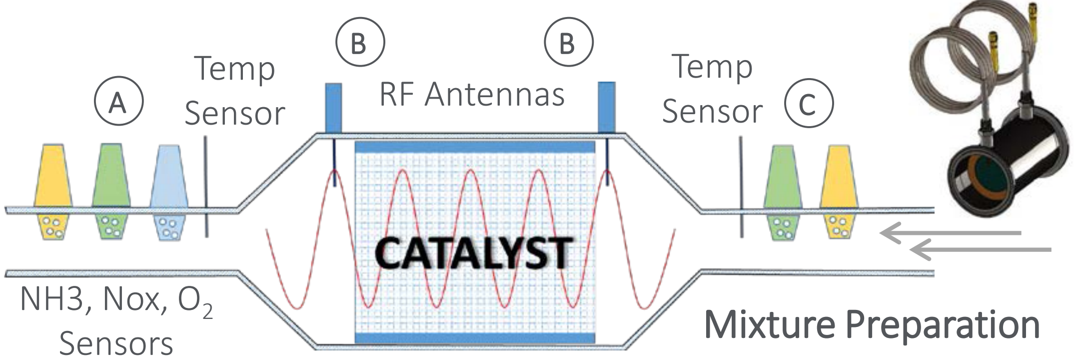



## RF Sensor Calibration

- ORNL bench reactor
- Gas mixture control and FTIR measurements pre- / post- catalyst
- Standard test protocols for catalyst preconditioning, loading, and desorption tests
- Calculated $NH_3$, $O_2$ storage levels supplied as reference for RF sensor calibration of SCR and TWC
- Standard core samples used at ORNL and CTS

## CTS Reactor Setup Mimics Production System Configuration for Performance Benchmarking

*Used for comparison of RF vs production exhaust sensors*

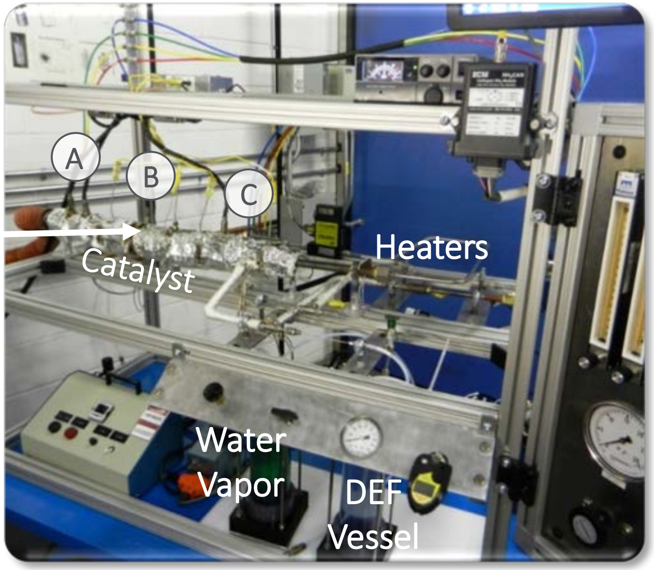



### Sensors

- RF Sensor
- NOx/$O_2$, λ
- $NH_3$ Sensors

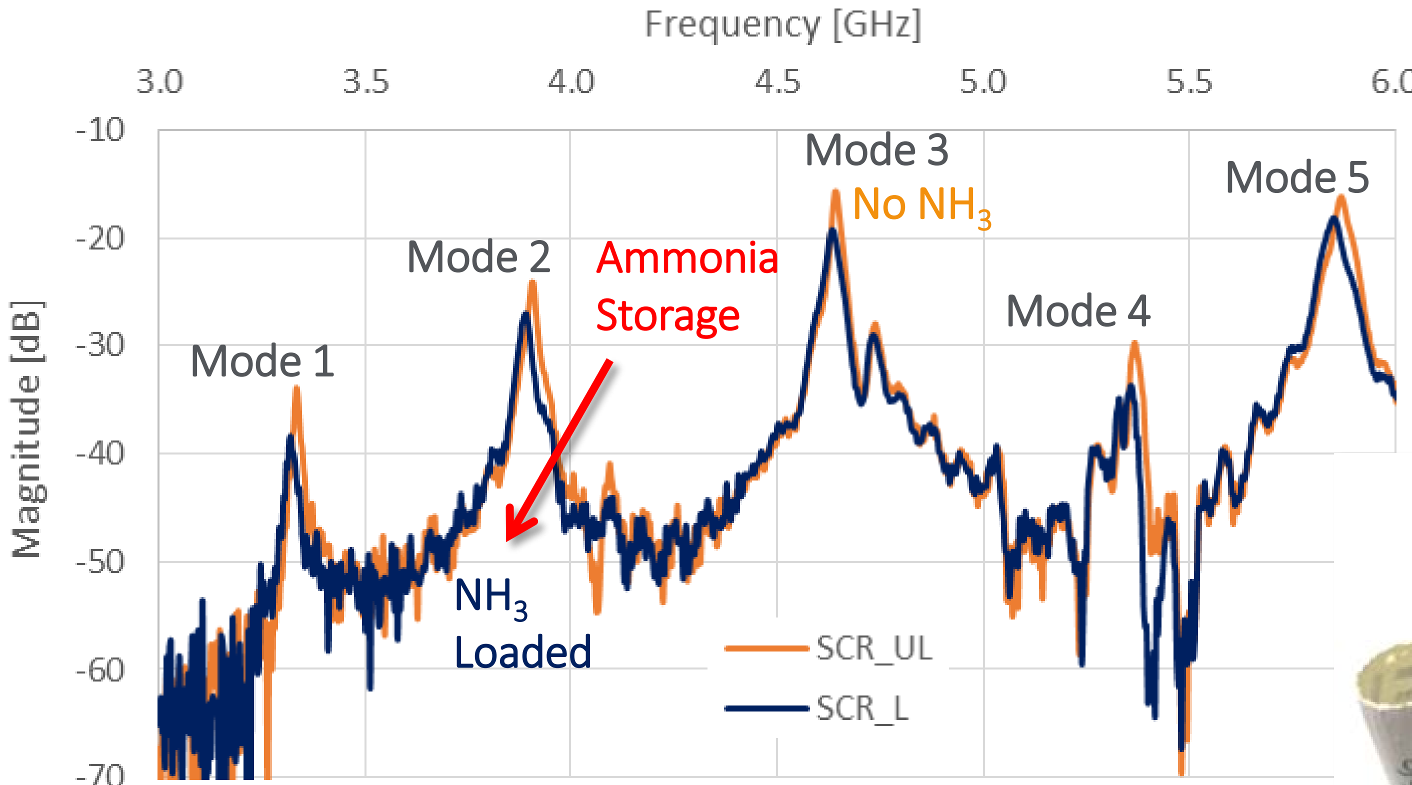
### Mixture Preparation

- $N_2$, NO, $NH_3$, $O_2$, $H_2O$, CO, $CO_2$, HC
- Temp: 100 – 550 °C
- Flow: 0 – 100 slpm



# Accomplishments –RF Response to Ammonia Storage on SCR

Ammonia storage measurements demonstrated on laboratory bench reactor

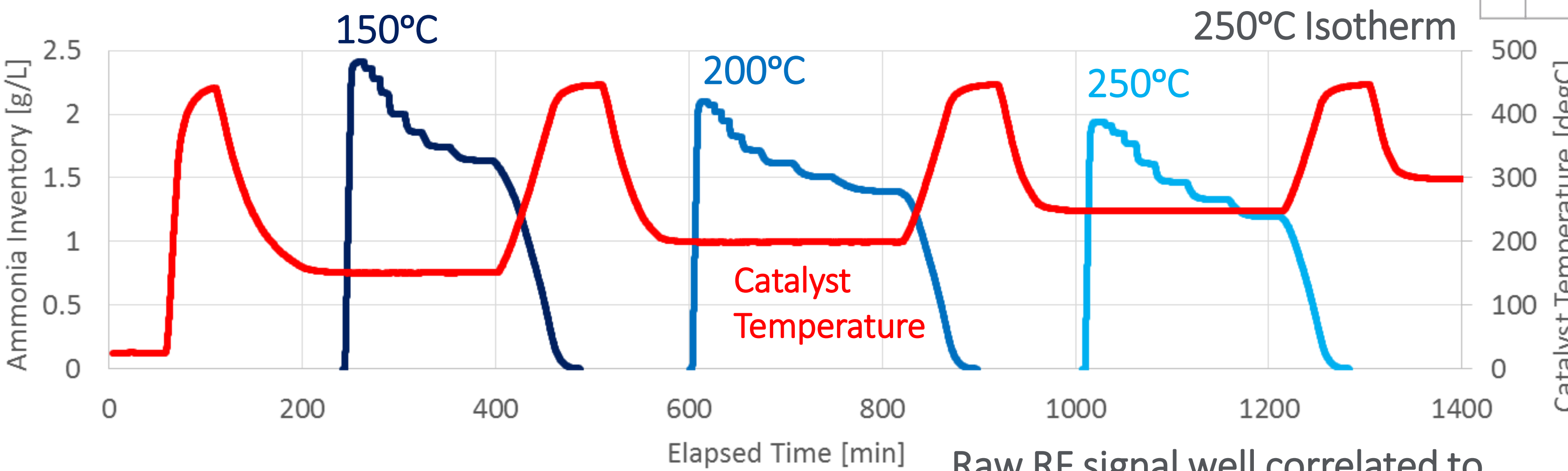



SCR core samples evaluated on bench reactor at CTS and ORNL


## Catalyst Bench Reactor Testing Confirmed $NH_3$ Impact on RF Signal

- Maximum 5 dB reduction in signal amplitude with $NH_3$ storage
- Fully-desorbed state (sharp resonant modes) – No ammonia storage
- Reduction in amplitude and shift in frequency with ammonia storage

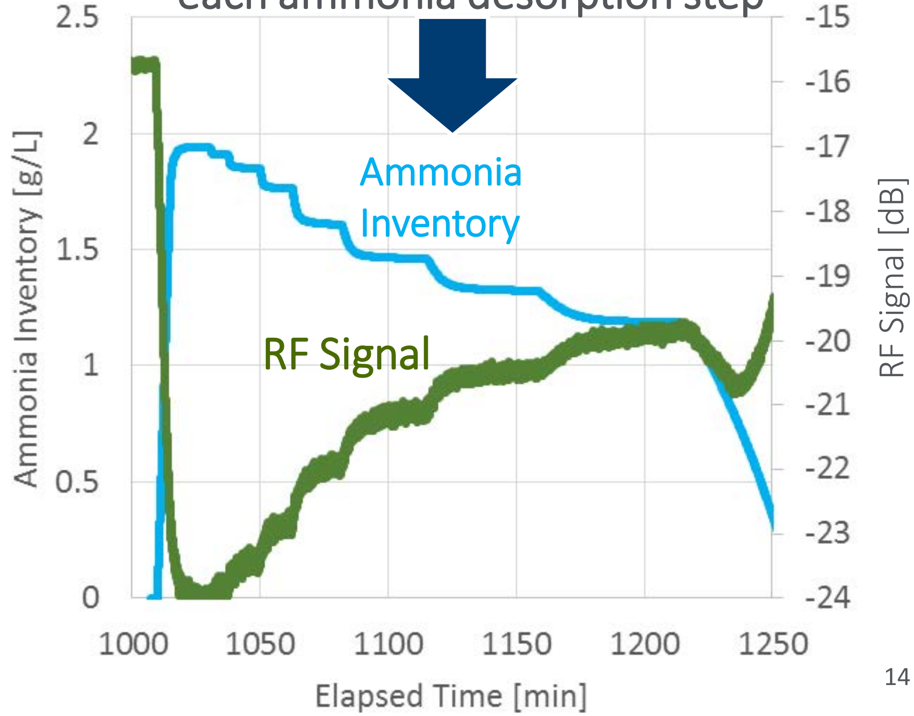
# Accomplishments – Temperature Compensation of SCR



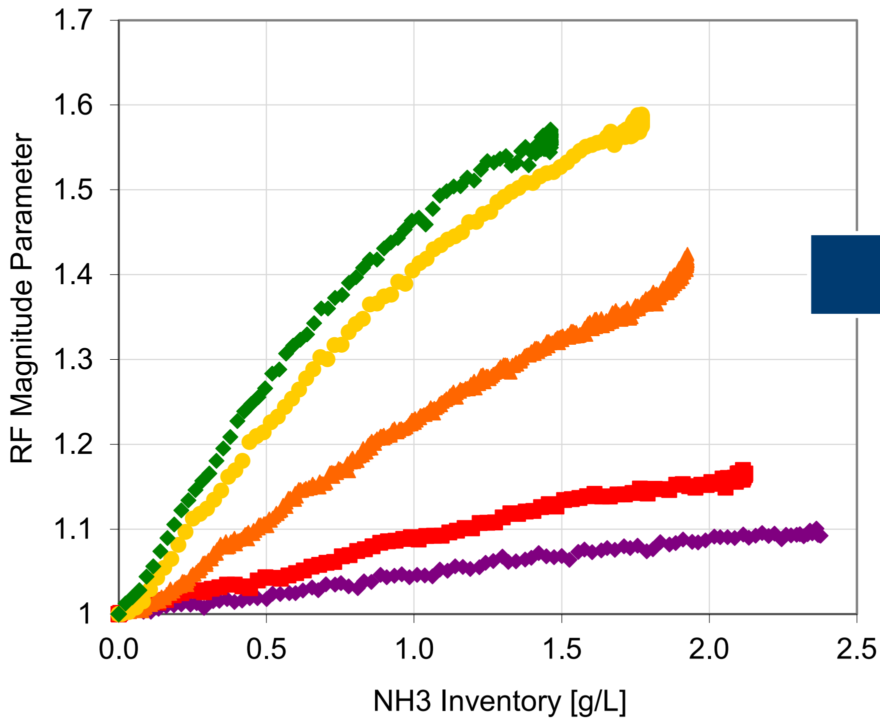

Raw RF signal well correlated to each ammonia desorption step

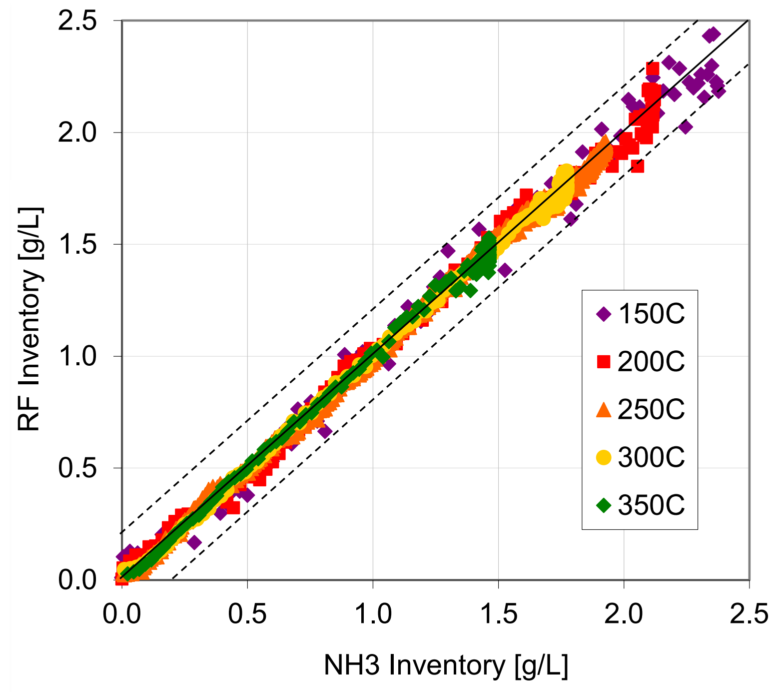
RF sensor calibrated for SCR performance using a series of desorption isotherm tests

- Catalyst loaded to saturation, then ammonia injection is reduced to allow for desorption
- High-temperature SCR regeneration performed between desorption isotherms
- RF response measured at each temperature to allow for incorporation of temperature compensation



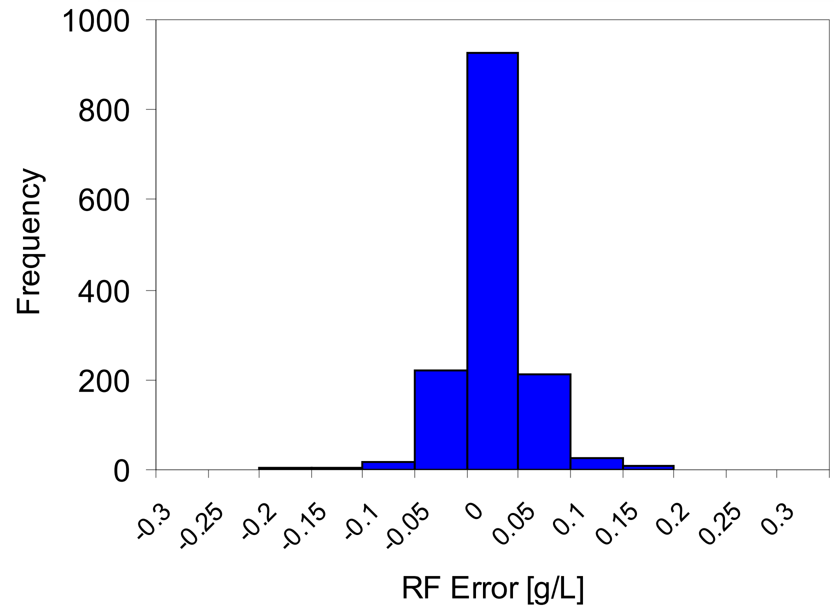
# Accomplishments – Ammonia Inventory Measurement with RF




## Go / No-Go Decision Criteria Achieved:

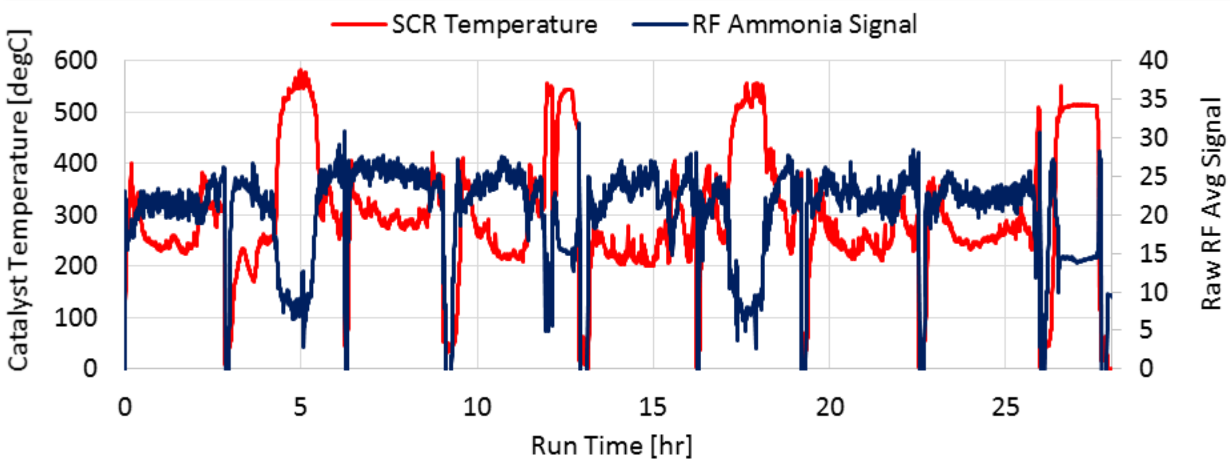
- Developed RF calibration for ammonia storage measurements including temperature compensation within 10% of full-scale
- Calibrated RF sensor for the SCR has a mean measurement error of **0.000 g/L** and a standard deviation of **0.036 g/L**

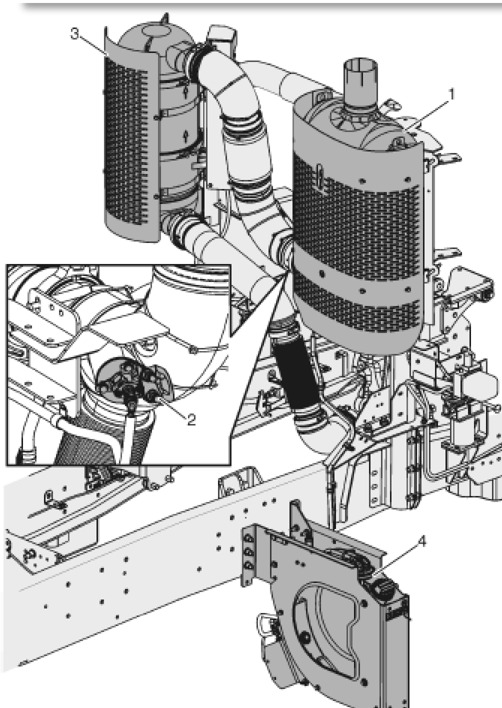


# Accomplishments - RF Measurement with SCR Confirmed On Vehicle

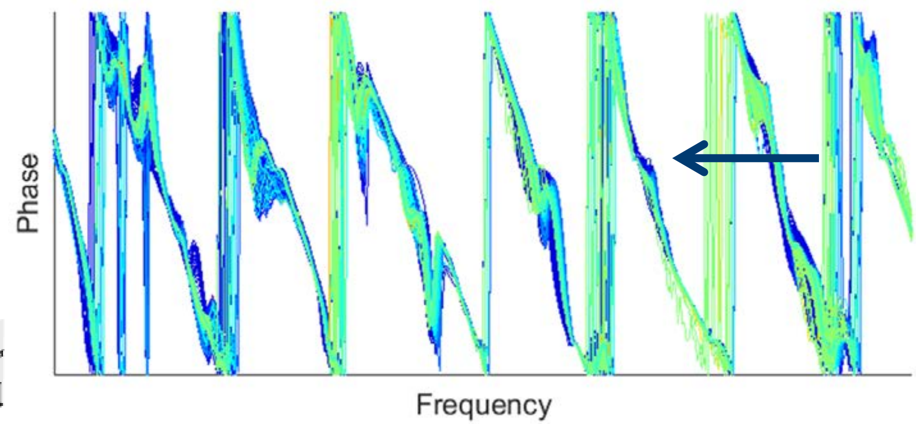
## Fleet Testing On Mack and Cummins-Powered Vehicles Since May 2016






### Phase Shift Correlated with Ammonia Storage




- Testing started with DSNY ahead of schedule
- Two Mack MP-7 equipped HD vehicles
- One Cummins ISB equipped MD vehicle
- New York City urban drive cycles

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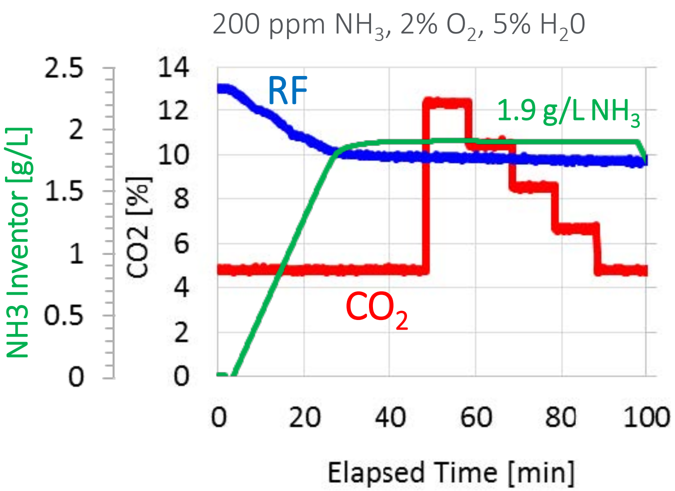
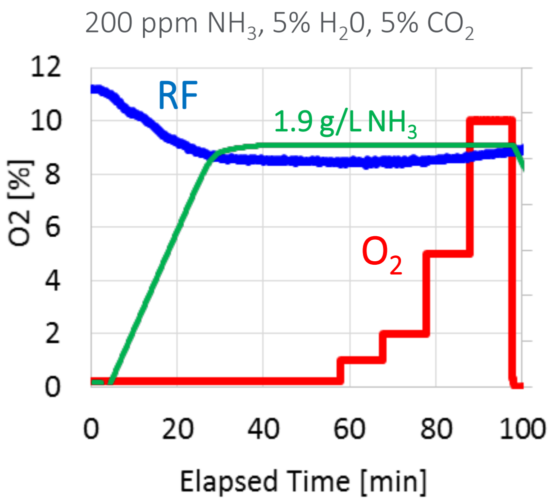
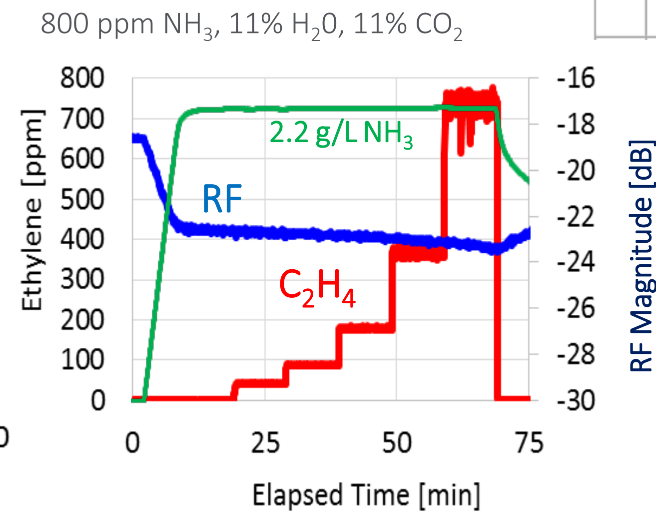
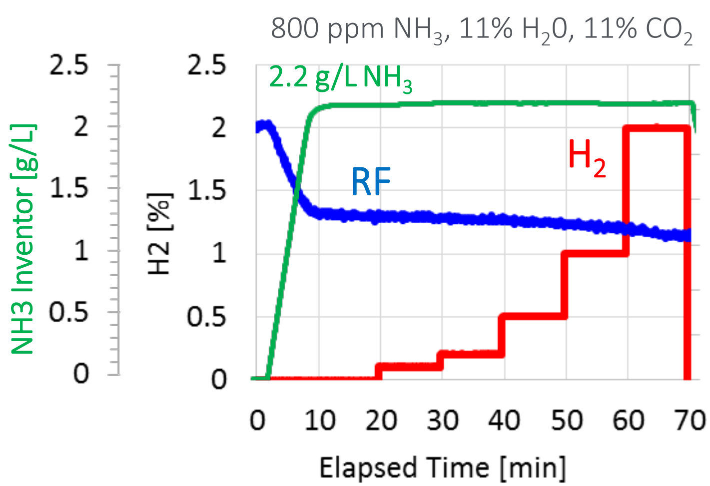
# Accomplishments – Analysis of RF Sensor Noise Factors

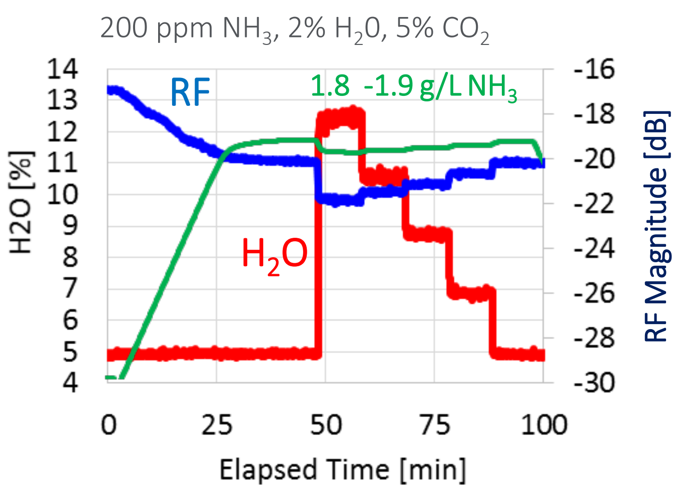
## Controlled variation of individual gas species to evaluate impact on RF response



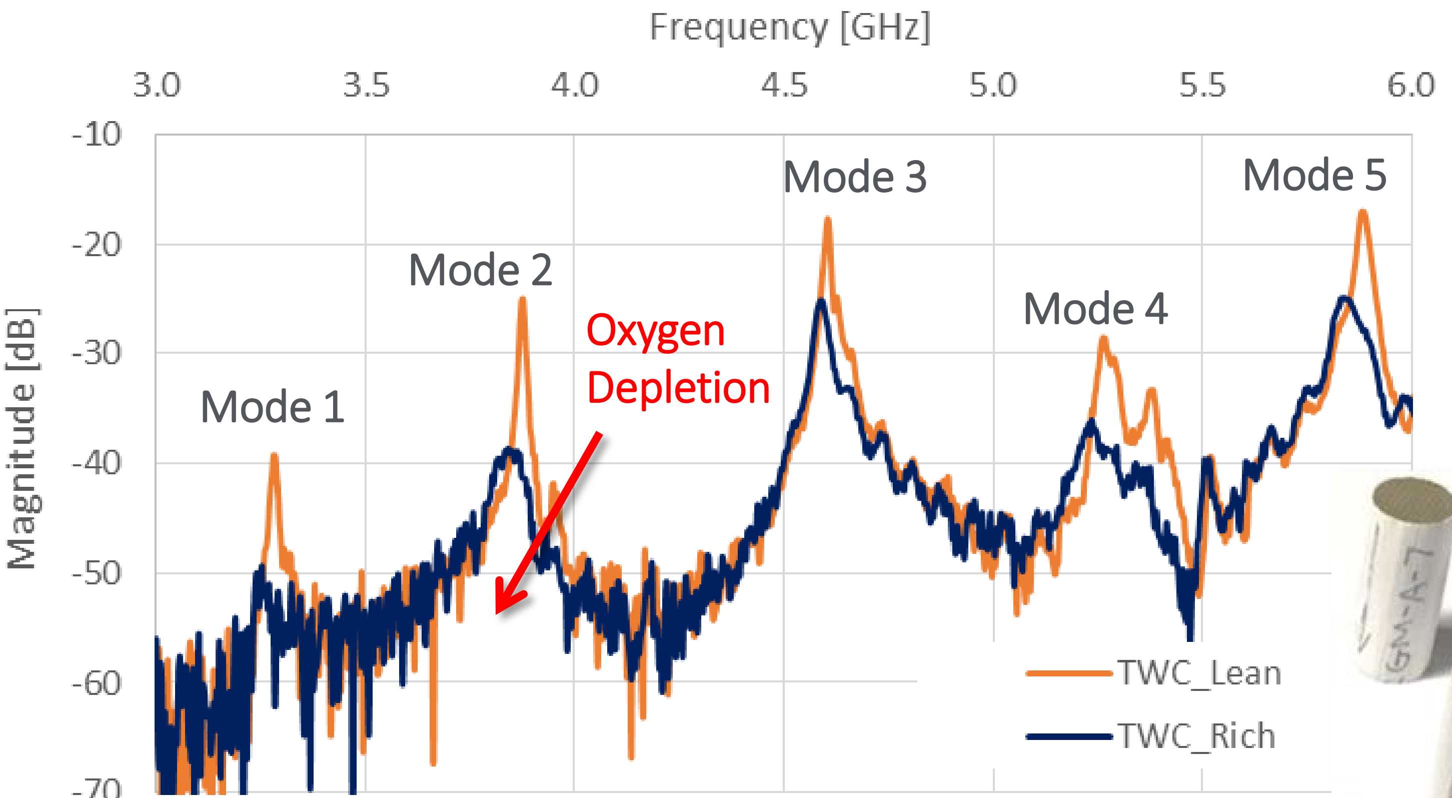

### Cross-Sensitivity

- No impact of $CO_2$ and $O_2$
- Small impact of $H_2$ and $C_2H_4$ at elevated levels
- Noticeable impact of $H_2O$ on stored $NH_3$ and RF signal

All testing conducted at 200 °C and 30,000 $hr^{-1}$ on ORNL bench reactor

# Accomplishments - Oxygen Storage Readily Detected on TWC

Oxygen storage measurements confirmed on laboratory bench reactor

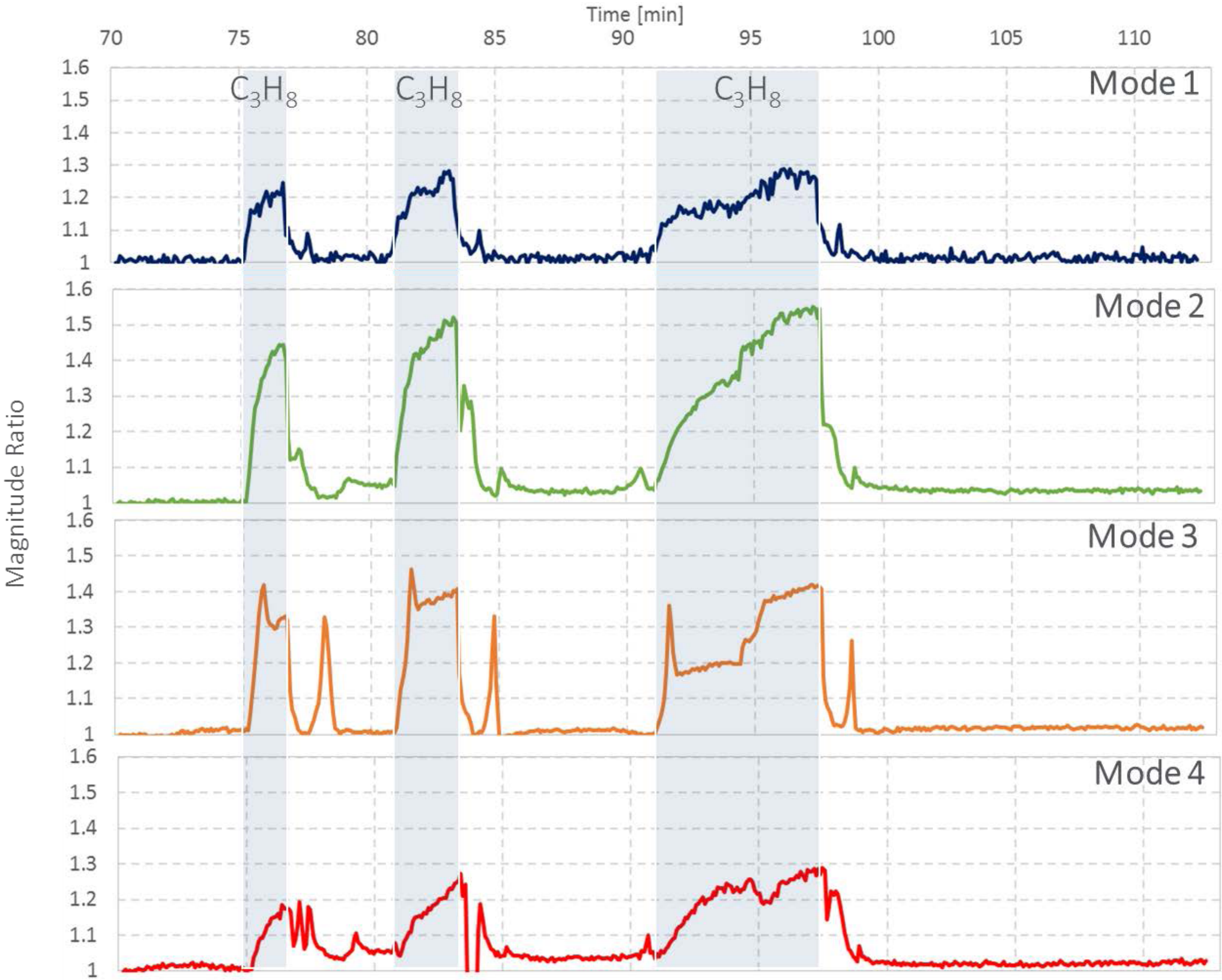



TWC core samples evaluated on bench reactor at CTS and ORNL


## Large RF Response to Change in TWC Oxidation State

- Lean Conditions: Oxygen storage inhibits Ce conductivity (sharp resonances)
- Rich Conditions: Oxygen depleted state results in large dielectric loss
- Impact on specific resonances function of local electric fields

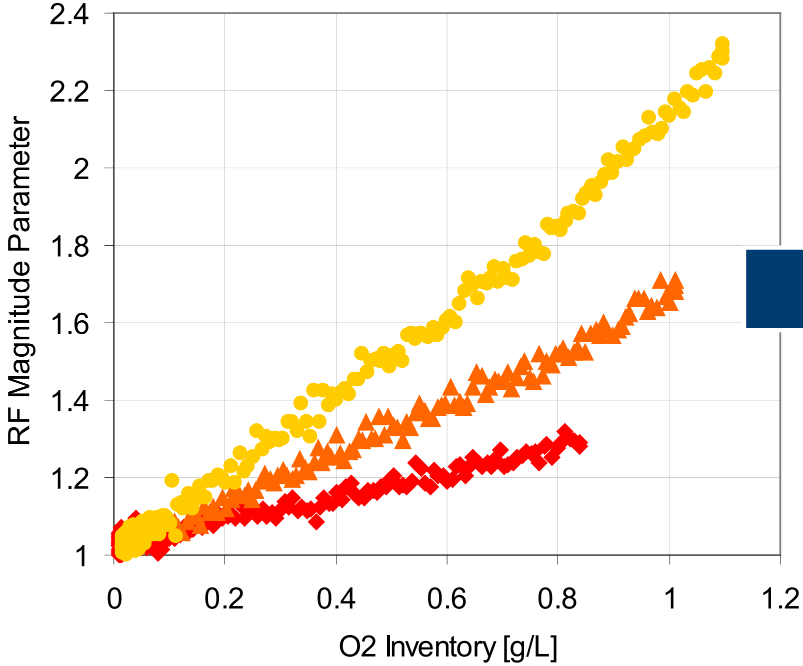
# Accomplishments - Response to TWC $O_2$ Storage / Depletion

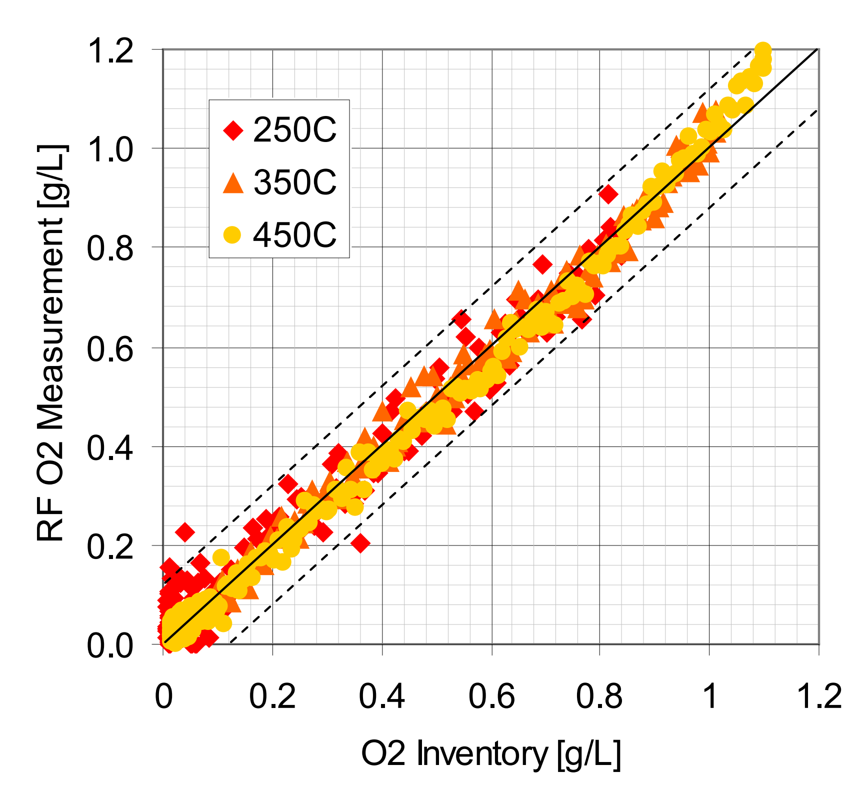


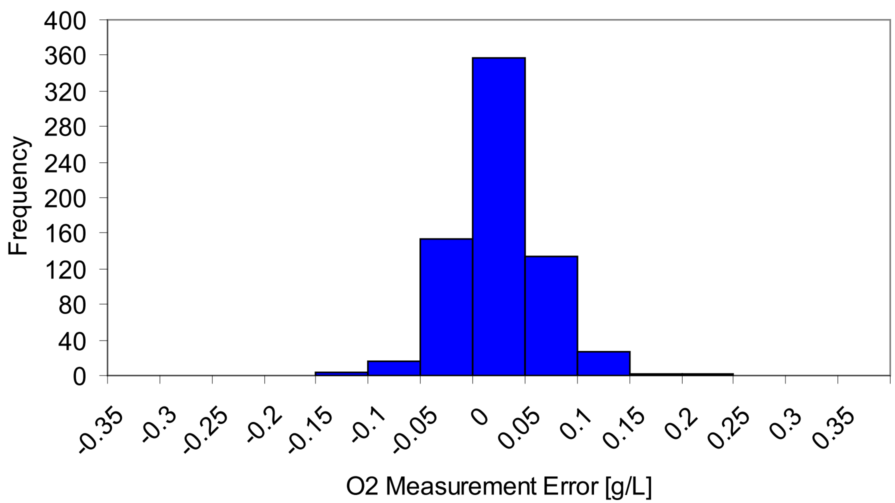

## RF Resonances

- RF resonance response to $O_2$ depletion
- Modes respond quickly when HC added to system and stored $O_2$ on catalyst is consumed
- Characteristics of each mode vary, possibly indicating spatial sensitivity of signal to $O_2$ consumption

# Accomplishments – Oxygen Inventory Measurement on TWC




## TWC Calibration Developed

- Developed RF calibration for oxygen storage measurements including temperature compensation within 10% of full-scale
- Calibrated RF sensor for the TWC has a mean measurement error of **0.000 g/L** and a standard deviation of **0.040 g/L**

# Response to Previous Year Reviewer's Comments

## Approach and Collaboration

### Approach
- Good approach building on previous successful RF soot (DPF) project
- Excellent extension of the RF technology, research covers the bases to develop/test technology, with a strong project team.

### Collaboration and Coordination
- Good collaboration with input from National Labs, OEMs, Suppliers

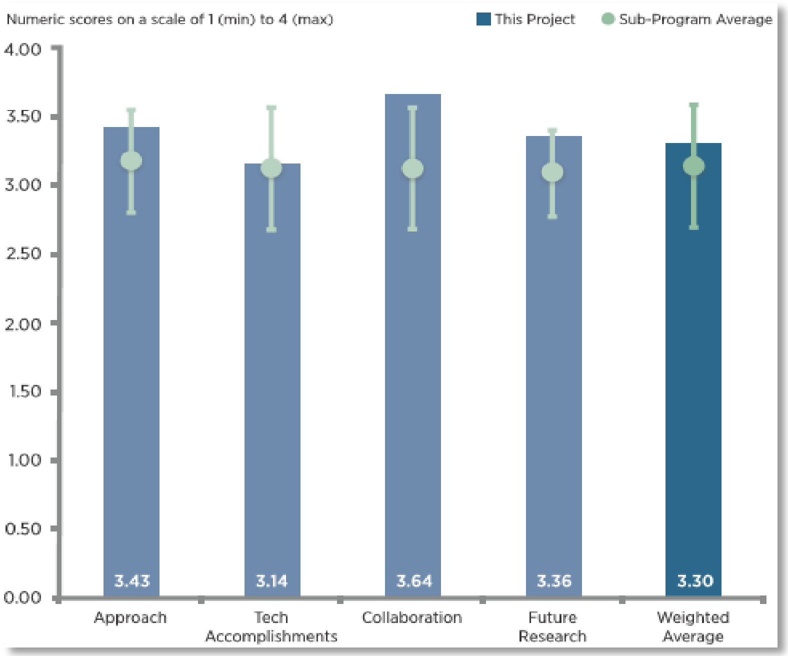
## DOE Relevance and Objectives

### Fuel Consumption and Efficiency
- Reducing uncertainty in aftertreatment effectiveness will improve efficiency
- Cost effective solution, maximizing aftertreatment performance will aid in reducing fuel consumption
- Demonstration of fuel savings needs to be focus, emphasize pathway from sensor development to fuel savings

## Accomplishments and Future Work

### Accomplishments
- Good progress for a new project
- Initial phase focused on sensor feasibility and testing, with promising results

### Future Work
- Need to focus on link between sensor development and fuel savings
- Good R&D plan to achieve project goals

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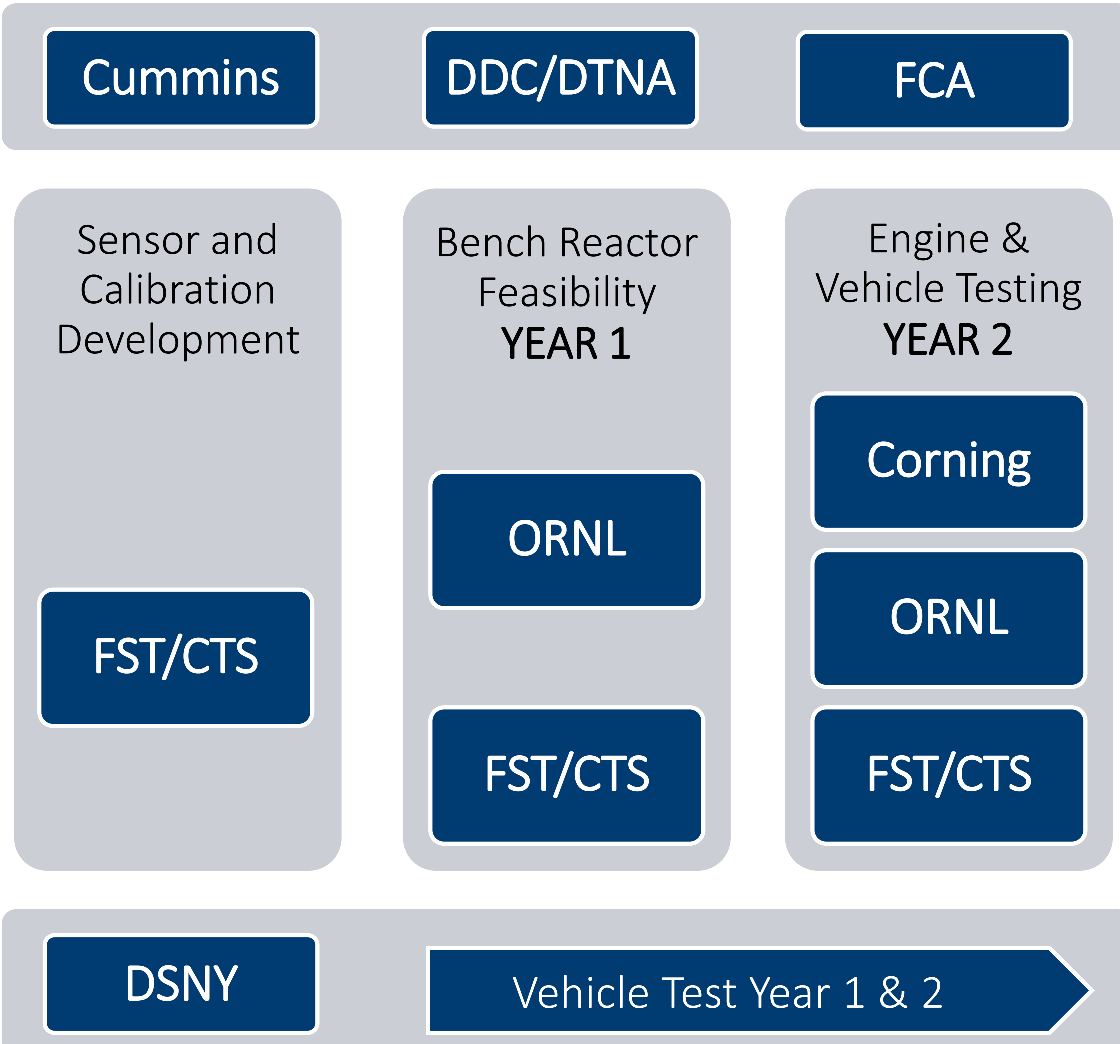
# Collaboration and Project Coordination




## OEM Technical Advisors

- Input on project direction, data review, sensor specifications
- Spans LD/HD, diesel & gasoline

## Core Project Team

- **FST/CTS** project lead: developing RF sensors for distribution to project team
- **ORNL** lead catalyst reactor testing in Year 1 and conduct LD engine testing in Year 2
- **Corning** provides catalyst and substrates in Year 1 and HD engine testing in Year 2 (cost share)

## Vehicle Fleet Testing

- Conducted with NYC Sanitation HD vehicle fleet
- On-road durability and performance evaluations

# Remaining Challenges and Proposed Future Work

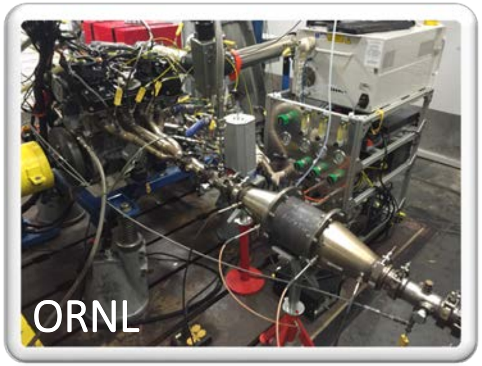
## Current Status

- RF sensing performance and feasibility evaluations for clean diesel, lean gasoline, and LTC catalyst applications is near completion in Phase I.
- Go/No-Go decision criteria achieved – demonstrated direct measurements of ammonia storage on SCR catalysts.

### Phase II Sensor Demonstration (2017/18)

- Distribute Optimized Sensor to Team for:
  - Bench Reactor Validation
  - Engine Dyno Test: HD & LD
  - Vehicle Fleet Test: HD
- Quantify Overall System Performance
- Develop Estimates of Overall System Efficiency Gains via RF Control
- Quantify System-Level Fuel Savings

### Focus on Efficiency Gains / Fuel Savings through Engine and Vehicle Tests


Preparations for full-size SCR dyno test at Corning (Diesel) and ORNL (Lean Gasoline)

# Summary

## Phase I Target for SCR Measurements Achieved

- Production-intent sensor developed and catalyst feasibility confirmed
- Clear path to commercialization to meet the overall project objectives

## Accomplishments in Phase I – Sensor Application Feasibility

- Applied models for RF cavity response to guide experimental design and data analysis
- Coordinated experiments with industry and national lab project team
- Confirmed feasibility to directly measure stored ammonia on SCR and oxygen on TWC
- Developed initial SCR and TWC RF sensor calibrations to meet project accuracy targets
  - Demonstrated $NH_3$ storage measurements from 0 to 2.5 g/L with $2\sigma = 0.072$ g/L [lab]
- Started vehicle fleet testing on heavy-duty and medium-duty vehicles ahead of schedule
- Conducted systematic analysis of noise factors for RF measurements

## Outlook and Project Impact

- RF sensing may provide a paradigm shift for emissions control by providing a direct measurement of catalyst state – optimize control and system diagnostics
  - Robust and low cost emission controls are needed to overcome key barriers limiting the widespread use of advanced combustion engines

# Thank You

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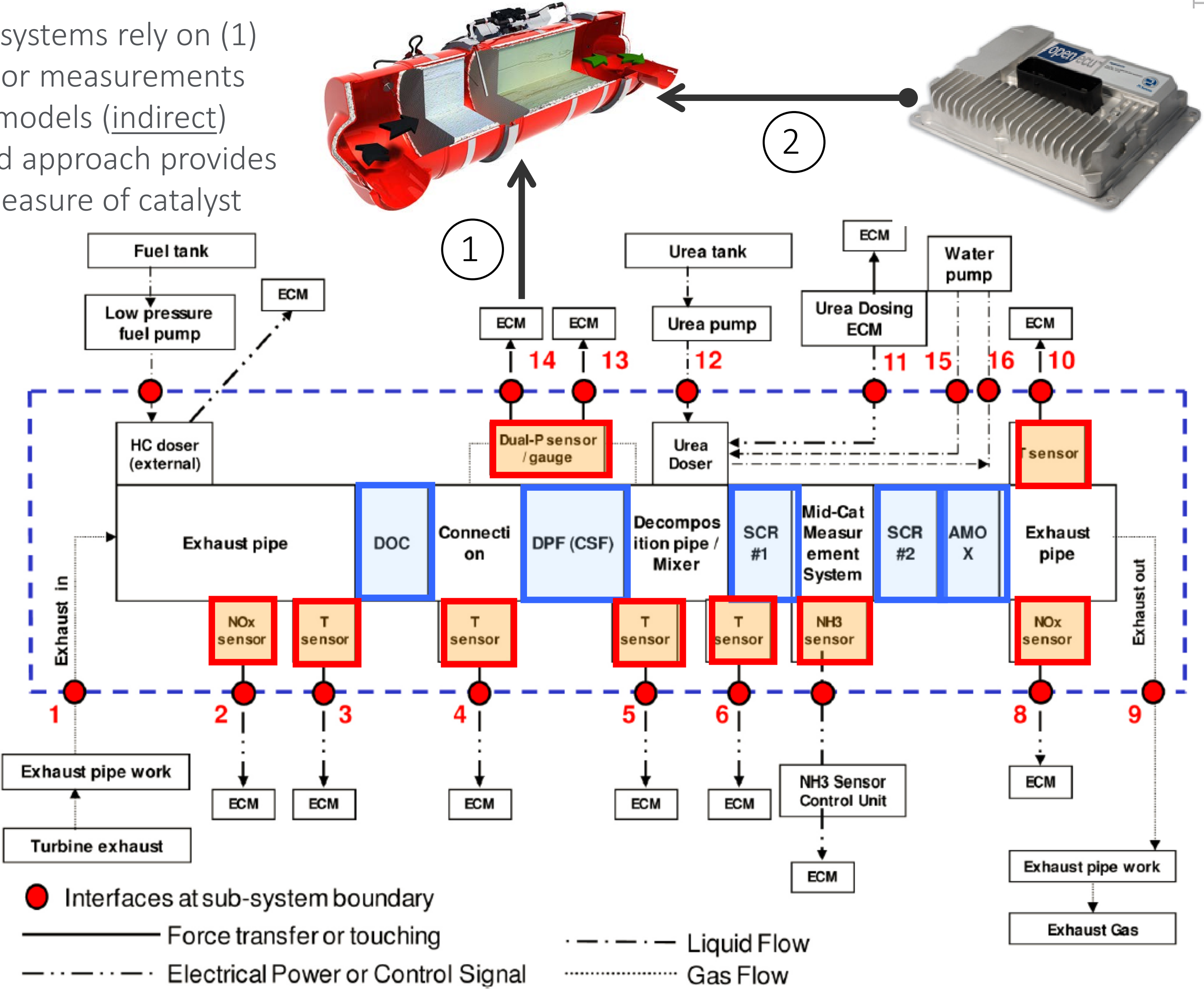
# Technical Backup Slides

# Challenge: Determination of Catalyst State

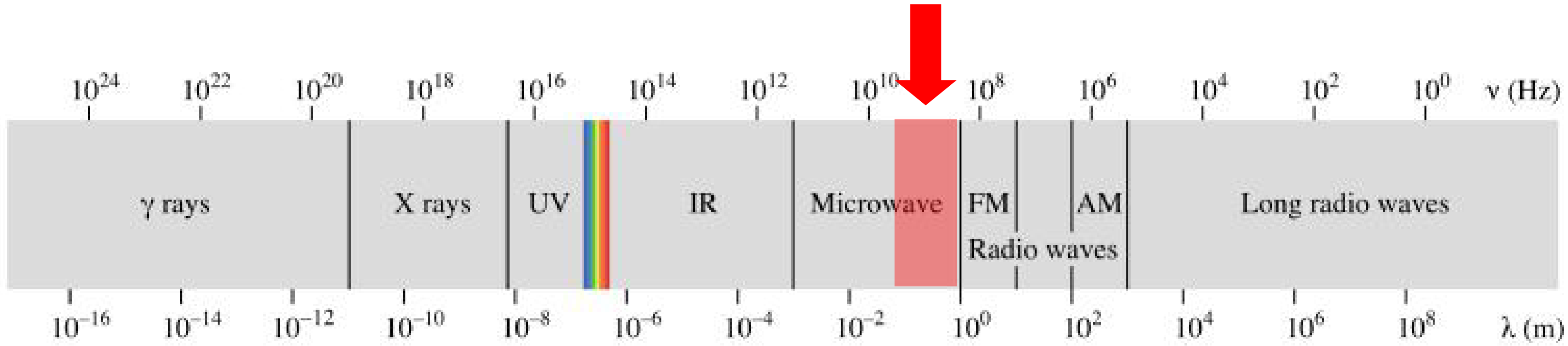
- Current systems rely on (1) gas sensor measurements and (2) models (indirect)
- RF-based approach provides direct measure of catalyst state




Stanton, D., "Systematic Development of Highly Efficient and Clean Engines to Meet Future Commercial Vehicle Greenhouse Gas Regulations," SAE Int. J. Engines 6(3):1395-1480, 2013

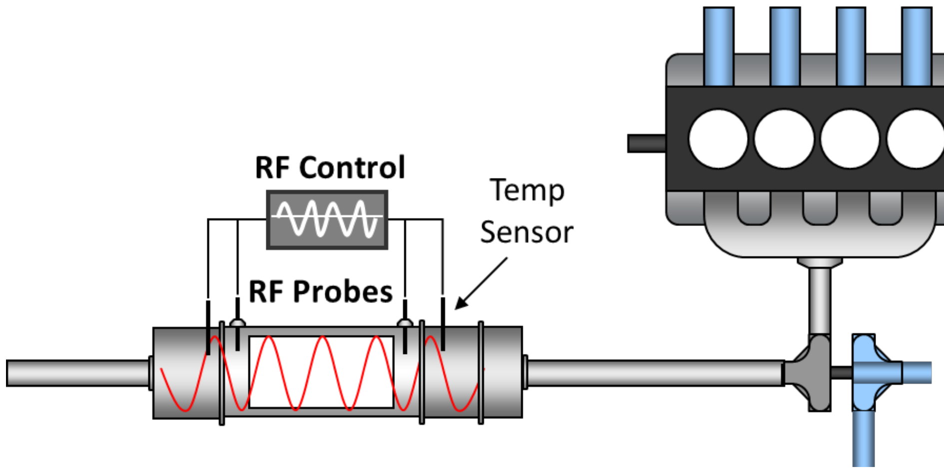
# RF Measurements and Material Dielectric Properties

Microwave Frequency Range




## Microwave Cavity Resonance

- Utilize filter housing as resonant cavity
- Resonant modes established in conducting cavities at specific frequencies
- Signal characteristics of modes affected by material through which the wave travels




**Signal Affected by Dielectric Properties of Exhaust Species**

$$\kappa = \frac{\varepsilon}{\varepsilon_0} = \varepsilon_r = \varepsilon_r' - j\varepsilon_r'' \qquad \tan\delta = \frac{\varepsilon_r''}{\varepsilon_r'}$$

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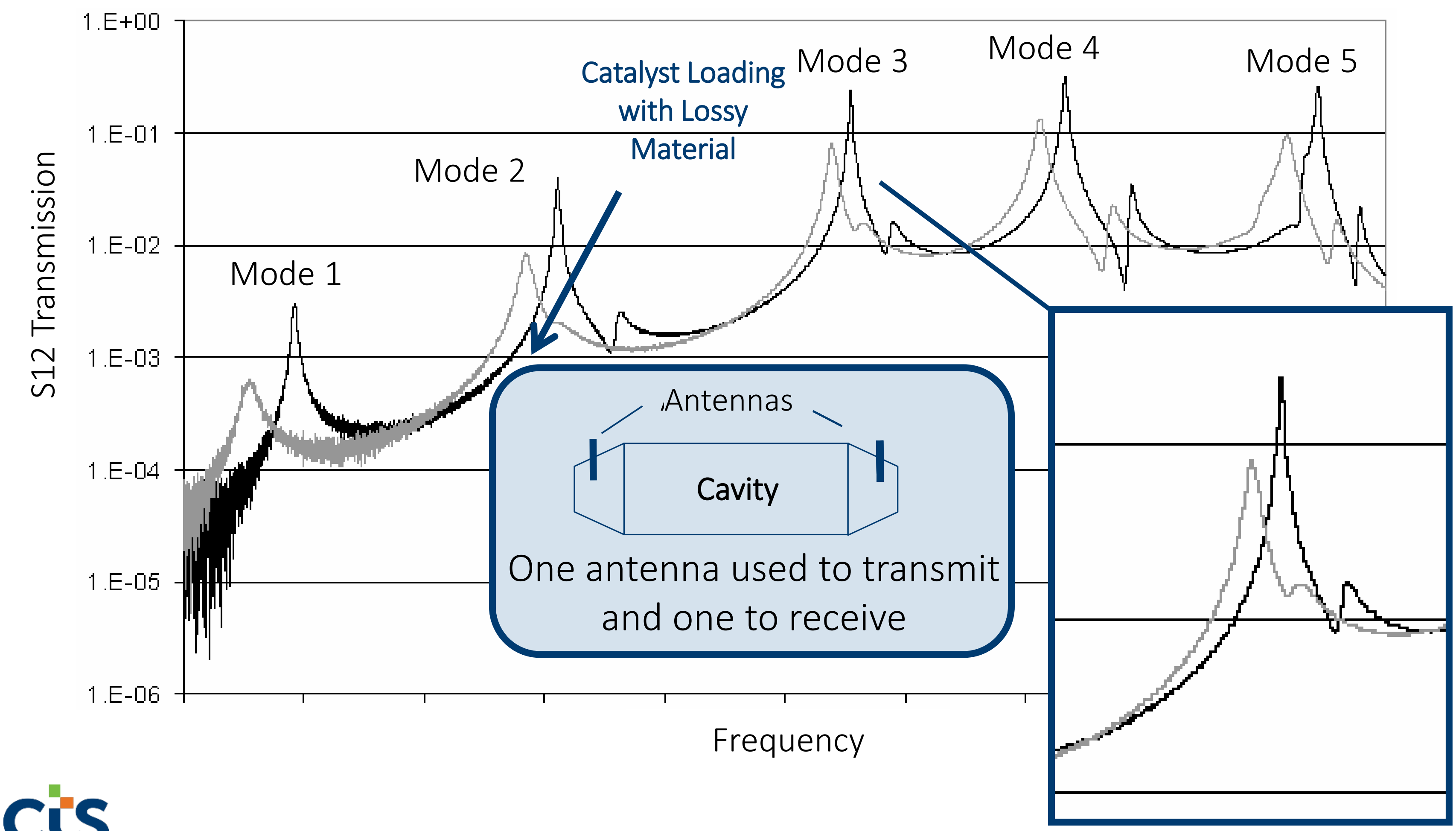
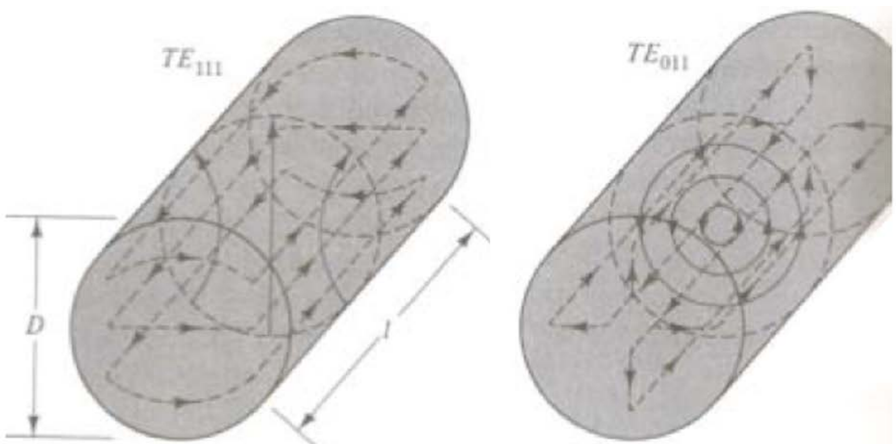
# Example of RF System Operation: Transmission

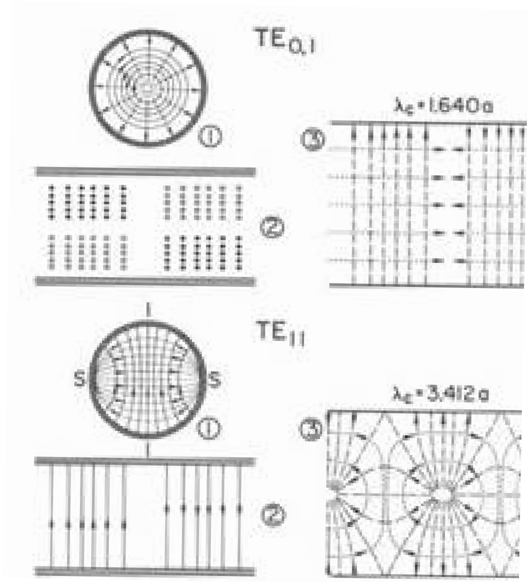
- Multiple modes exist in the cavity depending on frequency of operation
- Mode structure (field profiles, direction) depend on the geometry and the frequency



# Resonant Modes Provide Spatial Information

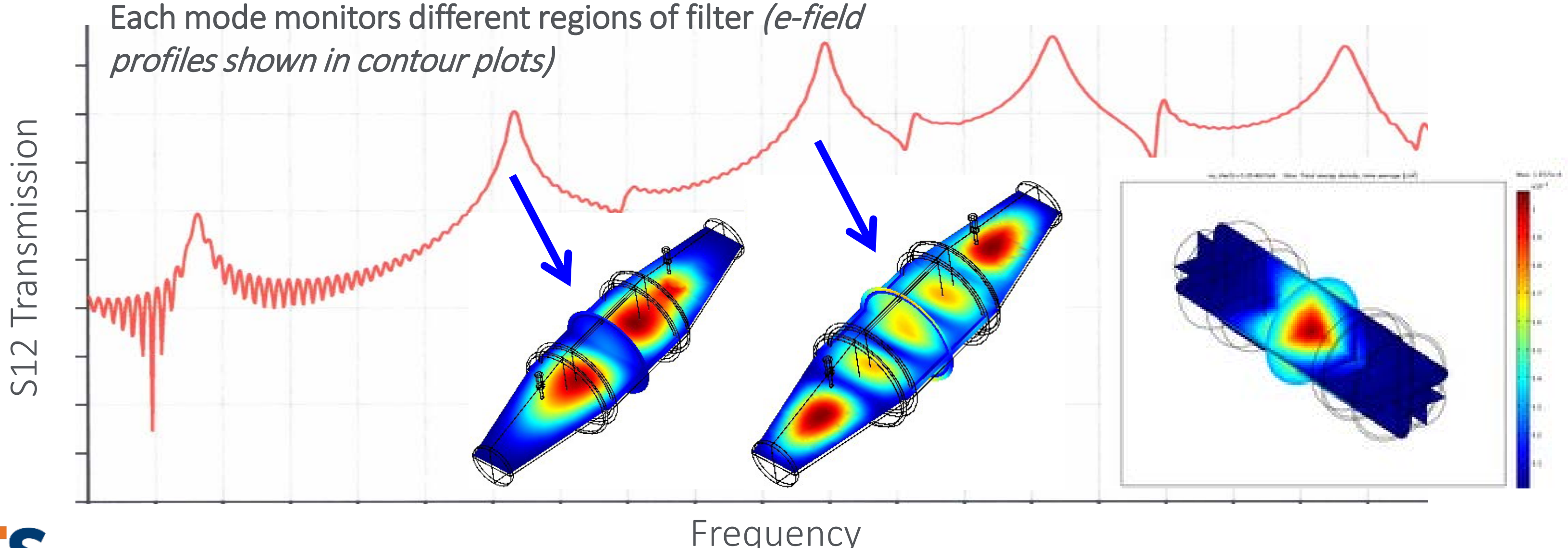
## Typical Resonant Mode Electric Field Profiles*




## RF System Models for Filter-Specific Geometries

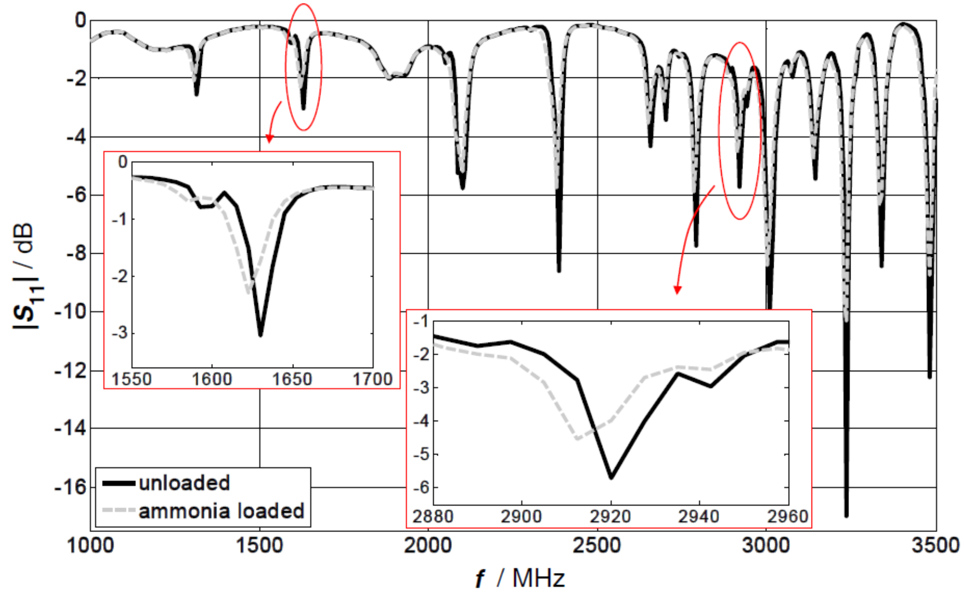
Each mode monitors different regions of filter *(e-field profiles shown in contour plots)*




* Adam, Stephen, F., Microwave Theory and Applications, Prentice Hall, Inc., Engelwood Cliffs, New Jersey, 1969.

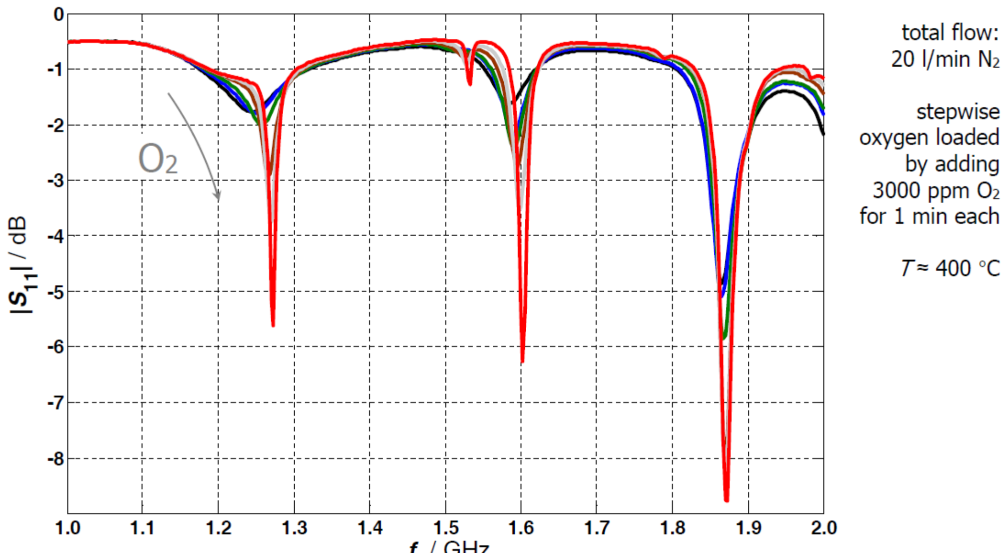
# Literature Review – Relevant Prior Work

## SCR:
Reflection (1 antenna) for unloaded and ammonia-loaded conditions at 300 °C




S. Reiß, D. Schönauer, G. Hagen, G. Fischerauer, R. Moos, Monitoring the ammonia loading of zeolite-based ammonia SCR catalysts by a microwave method, Chem. Eng. Techn., 34, 791-796 (2011)

## TWC:
Reflection (1 antenna) for oxygen storage on three-way catalyst at 400 °C




S. Reiß, M. Spörl, G. Fischerauer, R. Moos,
Realabgastauglichkeit einer HF-gestützten Automobilabgasdiagnose, G. Gerlach, P. Hauptmann (Hrsg.), 9. Dresdner Sensor-Symposium, 7.-9. Dezember 2009, Dresden, p. 263-266